PAPERS ON CLIMATOLOGY IN RELATION TO AGRICULTURE, TRANSPORTATION, WATER RESOURCES, ETC.

THE CYCLONIC DISTRIBUTION OF RAINFALL IN THE UNITED STATES,[1] ETC.

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That the importance of rainfall as a climatic element has long been recognized is shown by the fact that the 1910 volume of "British Rainfall" [2] marks the completion of 50 years of continuous activity by the British Rainfall Organization. This society, although supported wholly by subscriptions and dependent entirely upon voluntary observers for its records, now collects daily records of rainfall from nearly 5,000 stations in the British Isles and publishes the results in an excellent annual volume, which may well serve as a model for the treatment of rainfall data.

The earliest rainfall maps were probably those showing mean annual amounts of precipitation. These maps were followed in a short time by maps of the precipitation for periods shorter than the year, which were the month and later the season and later still the week. In the treatment of climatic data regular periods have obvious advantages. There is no doubt as to the beginning or the ending of a calendar period; if we begin at midnight on a certain date and end at midnight on another date, anyone can locate these times with perfect accuracy. A year or a month is definite, it can always be determined, and it is comparable with other years or months.

But the treatment of the data by mean annual amounts does not give any idea of the differences between years, and maps of individual years were soon introduced. These, however, do not give a clue to the conditions prevailing within the year; we do not know whether the rain comes in all parts of the year or whether it is limited to certain seasons. Maps of the monthly and seasonal amounts of precipitation were, therefore, introduced to give this necessary information in addition to that furnished by the annual maps. Such maps may be found in the Atlas of Meteorology,[3] and in the reports of the United States Weather Bureau,[4] and other meteorological services. Maps for the amounts of precipitation for months and seasons lead inevitably to the preparation of maps showing the departures from the mean for any given season. For the United States such maps have been drawn by the Weather Bureau.[4]

As the treatment of data becomes more refined there is a tendency to shorten the period. In the United States this has been accomplished by the publication of the National Weather Bulletin, which is issued weekly during the crop-growing season and monthly during the rest of the year. This bulletin shows by maps the amount of rainfall for the calendar week during the crop season and the amount for the month during the rest of the year; it shows also the departure of the individual week or month from the normal for the period as determined from all the preceding years of the record. It is probable that for many parts of the country a true normal has not yet been reached, but that the so-called normal is a longer or shorter period mean, depending on the length of time the station has been established.

The week seems to be as short a regular period as it is desirable to use. For a large part of the United States precipitation is to a great extent a cyclonic phenomenon, which means that its distribution within the week is accidental or due to controls which we can not as yet fully recognize. Besides this, the rainfall from a single cyclone in the United States may not, and frequently does not, all occur within the same calendar week for the whole country. The converse of the foregoing is also true; the rainfall of a single calendar week is frequently not all due to the same cyclone.

The close relation between the occurrence of much of the precipitation in the United States and that of cyclones leads to the suggestion that it is the cyclonic unit to which rainfall should be referred and by which rainfall should be studied.[5] The most obvious difficulty in the use of the cyclonic unit, beside its irregularity, is that not all the precipitation can be referred to cyclones. Besides the strictly noncyclonic rains, of which Clayton recognizes 5 classes, there are frequently considerable areas of rainfall, which, although cyclonic in character, can not be referred definitely to any existing cyclone as shown by the weather maps, owing to the weakness or complexity of the pressure conditions.

For a presentation of the rainfall record it will always be necessary to use the monthly and annual amounts, but for a wholly adequate knowledge of the conditions of precipitation for an individual month, season, or year in an extratropical region some use must be made of the cyclonic unit in rainfall. This was recognized by Loomis as is shown by his "Contributions to Meteorology," [6] where a number of individual cases of rain over the United States, Europe, and the Atlantic Ocean are studied in relation to the pressure distribution, movements of rain areas, and their relation to the other weather elements. Under the head of the "Weather of Baltimore," published in the Maryland Weather Service, typical cyclones are studied as they affect the distribution of the weather elements. Many weather maps are shown as types of weather conditions due to the varying pressure and other relations accompanying cyclones.[7]

In the annual volumes of "British Rainfall" each heavy rain occurring in the British Isles during the year is noted and the paths of the cyclones to which these heavy rains are due are studied in their relation to the distribution of precipitation. The results of the studies are published by the director in the annual volume of the organization and elsewhere.[8] The more important of these heavy rains are mapped each year and it is by these maps that the relations are best shown.

In view of the success of the British work and of the importance of the cyclonic rainfall in the United States,

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[1] This study was begun as a part of the work in the course in climatological research in Harvard University in 1910-11, under the direction of Prof. R. De C. Ward.

[2] British Rainfall annually since 1862. London. Edward Stanford.

[3] Bartholomew, J. G. Physical Atlas, Volume III, Meteorology. Edinburgh, 1899.

[4] See Monthly Weather Review, Washington, monthly.
United States Weather Bureau, Bulletin C, Atlas, Charts of Rainfall and Snow in the United States. Washington, 1894.
United States Weather Bureau, Bulletin Q, Climatology of the United States, by A. J. Henry. Washington, 1906.
United States Weather Bureau, Climatic Charts of the United States. Washington, 1904.
United States Weather Bureau, National Weather Bulletin, weekly during the crop-growing season and monthly during the rest of the year.
Maryland Weather Service, vol. 2, p. 362–363. Baltimore, 1907.

[5] For a discussion of the cyclonic unit, in climatology see Reed, W. G., jr., "The Study of Phenomenal Climatology," Quart. Jour. Roy. Met. Soc., vol. 36, pp. 39–48, 1910. Ward, R. DeC., "Suggestions Concerning a more Rational Treatment of Climatology," Rep. 8 Int. Geog. Congress, Washington, 1904, pp. 277–293. Hann, Julius, "Handbuch der Klimatologie," 3d Ed., Stuttgart, 1908, Vol. I, pp. 89–91.

[6] Loomis, E., "Contributions to Meteorology," Part III. Memoirs, Nat. Acad. Sci., vol. 5, 2d memoir, pp. 65–109, Washington, 1889.

[7] Maryland Weather Service, vol. 2, 1910, pp. 311–493.

[8] Mill, H. R., "Map Studies of Rainfall," Quart. Jour. Roy. Met. Soc., vol. 34, pp.65–86, 1908. "On the Unsymmetrical Distribution of Rainfall about the Path of a Barometric Depression Crossing the British Isles." Rep. 8 Int. Geog. Congress, Washington, 1904, pp. 393–396.

an attempt has been made to apply the cyclonic unit to the rainfall of this country and to show cyclonic distribution of this weather element by maps. The accuracy with which the British Rainfall Organization is able to work can not be approached in this country. The data for only about 170 stations appear on the Washington weather maps, but rainfall data are obtained at some 3,000 to 4,000 stations including those of the cooperative observers. The daily amounts for all these stations are published later in the Monthly Weather Review, together with excessive amounts for short periods of time. The lack of an organization to handle the data has made it impossible to make this study more than a preliminary suggestion of what it may be possible to do with rainfall data by the cyclonic unit in the United States.

This study has been made on the basis of the Washington daily weather maps because these furnished the data immediately and in a usable form and because it was deemed best not to attempt too much at the beginning. To use all the rainfall stations in the United States will probably require the preparation of a special map of the country, as all the published maps, which show the location of the stations and are large enough to carry the data, are confused by too much topographic and other detail. For a study of the data from the stations used on the daily weather map, the Washington base map is excellent; the size is convenient, being small enough for easy handling and yet large enough to carry the data; besides this the locations of the daily reporting stations are indicated.

Early in the study of the weather maps it was seen that many of the cyclones were not well enough defined to be followed across the country and that the relation between the more poorly marked pressure areas and the precipitation was in many cases very obscure. The method followed in "British Rainfall," which consists in taking the days of heavy rainfall, did not seem practicable for the United States and was abandoned after a brief trial. Cyclones are over the United States during parts of several days and not, as is generally the case in Great Britain, for one day only. In the United States rain is often falling from two or more cyclones at the same time and also from local areas of low pressure, which are perhaps embryo cyclones; some of these local low areas develop into cyclones and move across the country.

The cyclones whose tracks have been plotted by the Weather Bureau on the Washington daily weather maps are well defined both as to the low-pressure area and as to the path. These cyclones and such others as could accurately be followed by inspection of the Washington maps were selected for the purposes of this study. Only cyclones occurring between January 1, 1910, and October 1, 1911, are included in this work.

As yet no means has been devised for determining the beginning of a cyclone. There is often a rather large area of low pressure over the Basin and Rocky Mountain region in which smaller areas of lower pressure shift slowly back and forth with little apparent system. There may be occasional light rains in places, but in general the whole region is dry. Of course, there is no well-defined wind system under such pressure conditions. These conditions may continue for several days without much change in position and with little or no change in depth except for the weak shifting of the lower areas within the general low area. After a time the whole may develop into a single well-marked cyclone and move eastward generally along a northern track. In other instances, after the weak shifting of a large but shallow low area over the Basin region, a part may break off from the general low pressure area and move eastward. This may take place in the northern part of the general low area in which case the moving cyclone will usually follow a northern track; or in the southern part of the area, when a southern or Mississippi Valley track will usually be followed. In these cases the greater area of the large low pressure remains over the Basin to fill up or to develop other cyclones.

The most usual case seems, however, to be that in which the pressure shifts weakly over the Basin region, but is in general lower than the surrounding pressures; a new and distinct cyclone develops rather suddenly to the southeast of the general low pressure area and moves across the country leaving the larger area to die out or to continue. Figure 1 shows the movement of the center of the lowest pressure in a case of this kind in the latter part of April, 1911. No account is here taken of the numerous subsidiary low pressure areas, of which there were several at times. The cyclone which finally began to move eastward from southern Colorado was at no time a part of the larger low pressure area, but was developed in the vicinity of Pueblo, Colo. It is possible that there is no connection between the cyclone which moved eastward and the general low pressure area, but the suggestion is strong that the moving area was "induced" by the weakly shifting larger area over the basin. As this study was not directly related to the question of rainfall distribution it has not been pursued further, but it opens up an interesting field—that of the origin of cyclones in the United States.

A study of the maps immediately preceding those on which storm tracks are drawn shows that it is not by chance that most of the tracks begin east of the Rocky Mountains. That these conditions are not wholly due to the fact that there is but one map a day was to some extent shown by a study of tracings from the 8 p. m. Washington "scratch" maps. These maps, instead of showing that there was a systematic movement of the small areas of lower pressure, merely indicated increased irregularity and complexity of their movements. It is, perhaps, not safe to say that more frequent maps would not reduce these movements to some kind of order, but it may be said with some certainty that, for the purposes of such a study as this, the labor involved in the preparation of so large a number of maps would be out of all proportion to the results obtained.

While much of the rain of the Basin and Mountain region is cyclonic and should be classed as such, as should also much of the rain of the region farther west, no practical means has been found for including it with the proper cyclone. This is the general rule, but exceptions are by no means unknown; figure 2 shows the case of a cyclone which may be traced from off the coast of Washington eastward along a northern track to Newfoundland. Another case of a cyclone from the Pacific coast is shown in figure 3. This cyclone may be traced from off the coast of Washington southeastward across Washington, Idaho, and Wyoming, and thence to northern Louisiana; from here it passed eastward on a southern track across the Gulf States passing off the land near Hatteras. The cyclone was large and well developed both as to pressure and rainfall conditions throughout its passage across the country. A study of the storm tracks as plotted by the Weather Bureau will, however, show these cases to be the exception rather than the rule.

Many cyclones are delivered to the United States from Canada more or less completely formed, if a constantly reforming cyclone may properly be spoken of as complete. The moving conditions, which cause the advance of an area of low pressure, enter the United States from Canada between the Rocky Mountains and the Great

Lakes and move eastward, accompanied by rainfall and wind systems along the tracks in the United States. Figure 4 is a good example of a formed cyclone entering the United States from Canada. As a general thing the rainfall of these cyclones is not of great importance until they have progressed eastwardly far enough to come within the influence of the moist winds from the Lakes or the Gulf, but the pressure conditions are often as well marked when the cyclone enters the United States as at any time in its history while crossing the American continent.

The term "smear" has been introduced by Mill in his work on the rainfall from the cyclones crossing the British Isles;[1] this includes all the precipitation in an area which is due to the passage of a single cyclone. As this term is in the literature, it seems well to use it in a discussion of the cyclonic rainfall of the United States. In this paper the term "smear" will be used to designate the rainfall from a single cyclone in its passage across the continent, or the rainfall from two cyclones which unite and leave the continent as one. In a few cases it has been difficult to separate the smears of successive cyclones. As there is but one map available for each 24 hours, the front of the smear of the second cyclone sometimes overlaps the rear of the first cyclone, when two cyclones have been very near together. But this has not proved a serious matter in practice, and the difficulty would disappear in nearly all cases if more frequent maps were available. In the very few remaining cases it is probable that the rainfall is practically continuous and that the overlapping represents the actual meteorological conditions.

The proper treatment of thunderstorm rains offers another difficulty. In many cases these rains are located so close to the general rain areas of the cyclones that it is not possible to separate them. There is, however, some justification for including with the cyclonic precipitation those thunderstorm rains, which are closely related to the cyclone. Many of the thunderstorms in the United States are the result of the pressure or other conditions due to the cyclone, and the rain from these thunderstorms may properly be regarded as cyclonic precipitation. A case of an area of thunderstorm rains within the general rain area of a cyclone is shown in figure 5. This map is taken from the Washington daily weather map for July 23, 1911. It shows the conditions of a well-developed cyclone central over Iowa. The rain area has the appearance of the usual rain area of a cyclone of this type, but the map shows the area of thunderstorm rains by heavier shading. It will be seen that it is impossible to separate the thunderstorm rain from the general rain without considerably more data than are given by the daily weather maps.

The method adopted in treating thunderstorm rains for the purposes of this study has been to include in the cyclonic precipitation all such rains which occur within the general rain area of the cyclone, or which are continuous with the general rain area, and to exclude all other thunderstorm rains. In practice it has not been at all difficult to make this distinction; there have been practically no doubtful cases. The thunderstorm rain areas have been closely related to the cyclones or have occurred, isolated or in groups, clearly distinct from areas of cyclonic control.

In the study of the smears for Great Britain, Mill finds that there is usually a continuous strip of heavy rainfall (1 inch or more) across the island.[2] The earlier published maps do not show the areas for other amounts than 1 inch or more, and no distinction is made between the heavier and lighter falls in this area. In "British Rainfall, 1910," however, several maps of rain smears are shown on which the isohyets, or lines of equal rainfall, of 0.25″, 0.5″, 1.0″, 2.0″, 3.0″, and 4.0″ are drawn. On these maps the area of 1 inch and over is continuous, but the areas of greater amounts are very irregular.[3]

In the work for the United States the smear of rainfall for each cyclone was plotted on a map of the country.[4] The daily weather maps which showed the cyclone or any part of it were taken in order, and the sum of the daily amounts of precipitation due to the cyclone was plotted at the location of the station on the map. A convenient method of accomplishing this has been to plot at the location of each station on a blank map the rainfall from the cyclone for 24 hours, as shown by the daily weather map. The rainfall for the next 24 hours was plotted on the same map; at the majority of stations rain occurred from the same cyclone on more than one day; that is, rain at least lasted over the observation hour, 8 a. m., seventy-fifth meridian time, even if its duration was less than 24 hours. In this case the amount for the second day at the station was added to that of the first day, and the total amount for the 48 hours was plotted at the location of the station, replacing the 24-hour amount already there. This process was continued for as many days as there was any part of the cyclone over the country. In some cases there were stations where the precipitation from the cyclone under consideration all occurred within one 24-hour period, 8 a. m. to 8 a. m., seventy-fifth meridian time. In such cases the amount set down from the first map showing precipitation from the cyclone at the station was the final amount shown. In other cases there were three or even more days on which rain from the same cyclone fell at some stations, and here the amount was increased by that falling each day until the cyclone moved away from the station. After the last day the map showed at the location of each station the total amount of precipitation due to the passage of the cyclone in question.

The amounts of precipitation shown on the map by figures at the stations representing inches and hundredths could not be easily studied, and some method was necessary to get the figures and locations into groups so that the relations could be easily seen. The obvious and usual method of grouping such data to bring out the relations is the drawing of isohyets of convenient values, which method has been followed in this study. The values for which isohyets are to be drawn must, necessarily, be somewhat arbitrarily chosen. In the present case these values are the isohyet of "trace" or "T," that of 0.5″, that of 1.0″, and that of 2.0″; in some cases higher values than 2.0″ have been used, but for most of the maps the 2.0″ isohyet was the highest drawn. In the shading of the maps all areas of 2.0″ and over have been shaded alike. These values are the same as used by the Weather Bureau in the National Weather Bulletin, where they have proved satisfactory. It will be seen also that they are the same as those used in "British Rainfall" with the exception that there are a greater number of isohyets

[1] Mill, H. R., "Map Studies of Rainfall," Quart. Jour. Roy. Met. Soc., vol. 34, p. 75, 1908.
"On the Unsymmetrical Distribution of Rainfall about the Path of a Barometric Depression crossing the British Isles." Rep. 8 Int. Geog. Congress, Washington, 1904, pp. 393–396.
[2] Mill, H. R., "Map Studies of Rainfall," Quart. Jour. Roy. Met. Soc., vol. 34, pp. 65–86. 1908.
"On the Unsymmetrical Distribution of Rainfall about the Path of a Barometric Depression crossing the British Isles." Rep. 8 Int. Geog. Congress, Washington, 1904, pp. 393–396.
[3] "British Rainfall, 1910," Part 2, pp. [105]–[140]. London, 1911.
[4] A convenient map is the Washington daily weather base map: United States Weather Bureau "Form Map C."

used in the latter publication. Other values for the isohyets would undoubtedly make some differences in the appearance of the smears; but would not, of course, alter the facts of rainfall distribution. A theoretical objection to the use of these values is that they do not show a regular increase in the amount of precipitation as they would if they were drawn for every half inch of rainfall (0.5″, 1.0″, 1.5″, 2.0″, and 2.5″). Each isohyet except 0.5″, however, represents twice the depth of precipitation as the next lower line, and shows, to this extent at least, a regular increase in the amount of rain. But the test of such maps as these is their usefulness in practice, and the maps of rain smear have stood this test in England and for this study in the United States.

As stated above, the rain smears of the British cyclones show considerable continuous areas of 1 inch and over. In the United States the area for 1 inch and over does not show this continuity to so great an extent. Here the area of 1 inch or more is seldom wholly continuous. It is, however, probable this difference between Great Britain and this country is due mostly to the difference in area and the fact that no part of the British Isles is any great distance from the sea. It is also to be noted that the smears which show the really heavy falls of rain and which on the whole are the best developed and the most typical do show considerable continuous areas where more than 1 inch of precipitation was recorded during the passage of the cyclone. Figure 6 shows a case where the area of over 1 inch is considerably broken, and figures 3, 7, and 8 cases where this amount is continuous over considerable areas. Less frequently the areas for the lower values are not continuous. Figure 6 shows an extreme case of this sort. Here there are 4 distinct areas where the precipitation from the cyclone was over half an inch. Nearly all the cases studied show outlying areas of half an inch or more which are surrounded by areas of lighter precipitation; for examples, besides figure 6, see figures 2 and 9. In a few cases the areas in which rain has fallen are entirely separated by areas of no rain as is the case in figure 10.

The study of these maps seems to show that there are usually broad areas of more than half an inch of rainfall in most of our cyclones; there is the suggestion that the areas for the most part have a precipitation of a little less than an inch and that the isohyet of 0.8″ or 0.9″ would show rather large continuous areas. These lines, however, have not been drawn for the majority of the cases and no conclusion can be stated; the isohyets drawn have proven satisfactory for such a general study as this must necessarily be. That of 0.5″ may be taken to show the relations for the large areas. Of course, the accuracy reached by the British Rainfall Organization, where for maps of smears in England with a scale of about 250 miles to the inch, the boundaries of the areas of precipitation of different amounts are generally correct within the thickness of the lines,[1] can not be approached for this country. The boundaries of the areas on the maps accompanying this paper can not be taken as correct without a considerable allowance for error; most of the rain areas shown could be considerably altered and still be correct for the facts as known from the data taken from the daily weather maps, even from the Washington maps, which contain more data than any of the station maps. With the data from all the cooperative observers' stations as well as those from the regular Weather Bureau stations it is probable that it would be possible to draw the areas with an approach to the accuracy of the British maps, but even then this accuracy can not be equaled because there are fewer stations in a much greater extent of country.

That the regions of heavy rainfall should show a distinct relation to the Gulf of Mexico, the Mississippi Valley, the Great Lakes, and the Atlantic Ocean is to be expected. The Gulf influence is shown in figures 2, 3, 4, and 11; the Mississippi influence is marked in the cases shown by figures 2, 4, and 7, and comes out to a lesser extent in figures 3, 8, and 10. The importance of the Great Lakes is shown by all the smear maps, with the exception of figures 2 and 11, in which cases the tracks of the cyclones were far south. All the smears show the influence of the Atlantic Ocean, but the influence is most marked in the cases shown by figures 3, 4, 8, and 10. The Pacific Ocean shows no influence in most of the cases indicated by the figures. Its influence can be seen, to some extent, from figures 2, 3, 6, and 10, although in the case of figure 10 this influence was too slight to give much precipitation.

It will be noted that the relations between the distribution of precipitation and the bodies of water is not at all definite or regular. An inspection of the maps will show that these relations undoubtedly exist in a general way, but a closer study of them and of others which have been drawn does not show that any exact relation exists between the location of the areas of heavy rainfall and the water bodies. It is possible that a detailed study of the wind direction and velocity in relation to the rainfall-areas will bring out some relation which can not now be seen. As far as the study has gone at present the rainfall may be said in general to be heavier in the vicinity of the great water bodies than it is far from them, but no more exact statement seems to be justified.

There is probably some relation between the regions of heaviest precipitation and the storm tracks. The cyclones shown in figures 2 and 11 have tracks which are rather far south, and these two cyclones show important precipitation in the Gulf and none in the Lake regions; but figure 4 also shows heavy rainfall in the Gulf region, although the storm passed on a northern track; it should be noted, however, that in the latter case the heavy rainfall is due in part to thunderstorms. This same difficulty existed on all the maps studied. The paths of the cyclones in the period studied have been so varied that no classification of them has been practicable. It is possible to recognize the northern and southern tracks and a series of tracks between them, but so far no relation of importance has yet come out except in such cases as are shown by figure 11, where an extreme southern track gave precipitation only in the Gulf and not in the Lake region. In most of the cases studied the area of heavy rainfall was not far from the center of the track; the maps, figures 2, southern cyclone only, 4, 8, and 9, show heavy precipitation on the track of the cyclone. Perhaps there are other cases in which the areas of heavy rainfall are on the track; where the centers are charted only once in 12 hours there is often considerable uncertainty as to their location between the times of observation. If Loomis is right in supposing that there is a tendency for the cyclone to move toward the area of heaviest precipitation,[2] and there is no reason to think that there is not at least a tendency of this sort, we should expect to find the path near the areas of heavy rainfall. It must be borne in mind in this connection that the amounts shown by the rain smears here figured are the totals for the whole time of the passage of the

[1] Mill, H. R., "On the Unsymmetrical Distribution of Rainfall About the Path of a Barometric Depression Crossing the British Isles." Rep. of Int. Geog. Congress, Washington, 1904, p. 393.

[2] Loomis, E., "Contributions to Meteorology" (revised). Memoirs Nat. Acad. Sci., vol. 3, pt. 2, pp. 41-42, Washington, 1886.

cyclones and that in the case of heavy rain falling to the westward of the center of the cyclone there are tendencies at work, those which cause the general eastward drift of these whirls, to prevent the movement of the center backward toward these rain areas.

Cases where the areas of heavy precipitation are found at a considerable distance from the track of the cyclone are by no means uncommon. Figures 6, 10, Atlantic coast rainfall, and 7 are examples of this condition. In the case shown in figure 7 it is possible that the heavy rainfall is nearer the track in eastern Canada for which the rainfall is not shown in the figure, but there is a considerable area of heavy precipitation in the United States at some distance from the track. Figure 4 shows a considerable area of very heavy rainfall located far from the track; but in this case thunderstorm rains are responsible in some degree, and it is not, therefore, a typical case.

In cases where the heavy rainfall occurs on the track or near it we should not expect to find the rain area symmetrical with respect to the track. There should be a greater part of the area of heavy rainfall on the side of the track toward large water bodies or the side from which the rainy winds come. Mill has shown that this is the left of the track for the British Isles.[1] In the eastern United States the great supply of water, the Atlantic Ocean, lies to the right of most of the tracks and we should expect to find the areas of heaviest precipitation on that side. That this is often the case has been shown by the examination of the smear maps. Examples of smears which show the heavier rainfall to the right of the track are given in figures 3, in the area west of the Rocky Mountains, where the water supply is the Pacific Ocean; 6, although in this case only half the record is shown, the rainfall for Canada not appearing; 7; 10, precipitation along the Atlantic coast; and 11.

The Great Lakes present such an important region of abundant water that their influence should appear in the case of the smears of cyclones whose tracks lie near them. Their influence will simply strengthen that of the Atlantic Ocean in those cases where the tracks lie to the north of the Lakes. But when the track is south of the Lakes we should expect to find their influence shown by the location of areas of heavy rainfall to the left of the track. That this is the case is shown by such smears as those shown in figures 2, although here there is also the influence of the cyclone passing on the northern track which is perhaps responsible for all the precipitation in the Lake region; 3, if the rain area is not so far away from the Lakes that the influence of the Mississippi must be responsible for it; 4; 8, rain area is not far from symmetrical, but there is a suggestion of larger and heavier fall to the left of the track—this is the only case studied where there was an approach to symmetry; 9; and 10, rainfall in Michigan is to the left of the track.

The maps selected for the accompanying figures are typical of all the maps drawn. They seem to show every relation possible between the rain areas and the storm tracks and between the rain areas and the important water bodies. Every relation expected occurs, but there seems to be as yet no classification which will reduce the relations to a system. Although a large number of maps were drawn the conclusions which can safely be drawn are few. The rain areas may best be described as "patchy," the areas of heavy rain being for the most part scattered. Most of the smears show several areas of heavy rainfall rather than one connected area, but in the best-defined cyclones there seems to be a tendency to rather wide areas of heavy fall. The "patches" of heavier fall are usually connected by areas of lighter fall and are, for the most part, not separated by regions without rain. The smears bear a rather close relation to the important bodies of water; but just what this relation is has not, as yet, been determined.

The writer feels confident that a larger number of stations would show even greater variations in the areas of heavy rainfall, as this variation is now the most striking in that part of the country where there are now the most stations per unit area. The study of rain smears, made from maps on which the rainfall data for selected cyclones from all the regular and cooperative stations of the Weather Bureau have been plotted, is certain to lead to valuable results in advancing the knowledge of the cyclonic relations in the distribution of our most important weather element. The amount of work is large but the results will surely justify the undertaking, if the cyclones are carefully selected by a preliminary study of the daily weather maps.

The relation between the heaviest rainfall and the movement of the cyclones has been referred to on page 14. This relation does not come out directly from the study of the smears. If the amounts shown by the first weather map after the beginning of the cyclone are plotted and maps for the cumulative amounts are made from each weather map during the passage of the cyclone, it is probable that the suggestion that the center tends to move toward the area of heaviest precipitation can be tested. This, however, involves a study, which, although of great value, is not the same as the study of the smears; but it could be carried on to advantage with the study of rain smears. The two studies would probably be of considerable help to each other. There are probably other relations which will appear from a study of maps of cumulative amounts of precipitation daily from each important cyclone which do not come out from the study of the smears alone.

When the smears are studied in connection with the monthly and weekly rainfall maps and the maps of the departures from the means, the effect of a single important cyclone may be seen. The smear from a single cyclone is, of course, sufficient to strongly influence the whole distribution of rainfall in a week; and a heavy smear may show strongly on the rainfall map for the month, especially if it is in an unusual position.

Maps of the smears of our more important cyclones will greatly increase our knowledge of the rainfall relations of the United States. Rain smear maps can never replace the monthly and annual maps and will probably never wholly supersede the weekly maps of the crop season, because these maps include all rains some of which are noncyclonic and some, while cyclonic, are not closely enough related to particular cyclones to be plotted as smears. It is probable that over a large part of the country the greater part of the precipitation is the result of well-defined cyclones and the rain smears of these cyclones will show the rainfall relations much more nearly as it actually occurs than does the present method of monthly amounts, where the individual cases are covered and obscured in the means. When the study of rainfall in the United States reaches the point it has obtained in Great Britain through the efforts of the British Rainfall Organization, maps of rain smears, or something equivalent and accomplishing the same purpose, will become an essential part of the discussion of the rainfall relations for the greater part of the country where the cyclonic unit is the controlling factor in the weather.

[1] Mill, H. R., "Map Studies of Rainfall," Quart. Jour. Roy. Met. Soc., vol. 34, pp. 65-86, 1908.
"On the Unsymmetrical Distribution of Rainfall About the Path of a Barometric Depression Crossing the British Isles," Rep. 8 Int. Geog. Congress, Washington, 1904, pp. 393-396.

FIG. 1.—Movement of the center of lowest pressure over the Mountain and Basin Regions, Apr. 25 to 28, 1911; and the position of the center of the cyclone developed in Colorado, Apr. 28, 1911.

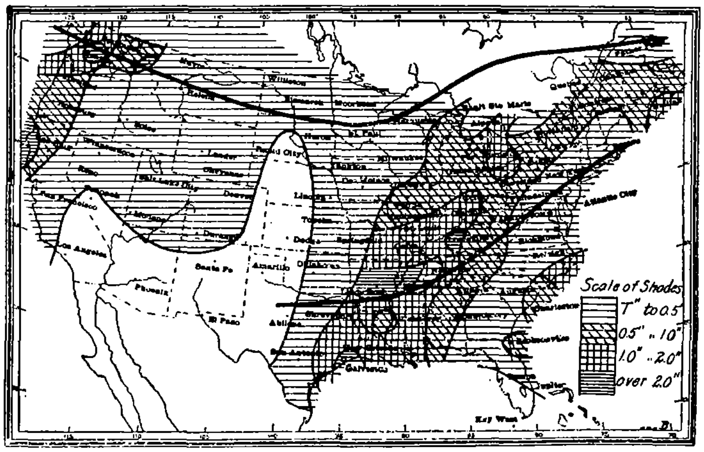

FIG. 2.—Path of a cyclone Feb. 22–Mar. 1, 1910, from the Pacific Ocean to the Gulf of St. Lawrence on a northern track. Precipitation from this cyclone in the Pacific northwest and in the Great Lakes region. Heavy precipitation in the Gulf, Mississippi Valley, and Lake regions from a second cyclone on a more southern track. Heavy precipitation from this second cyclone is on and to the left of the track.

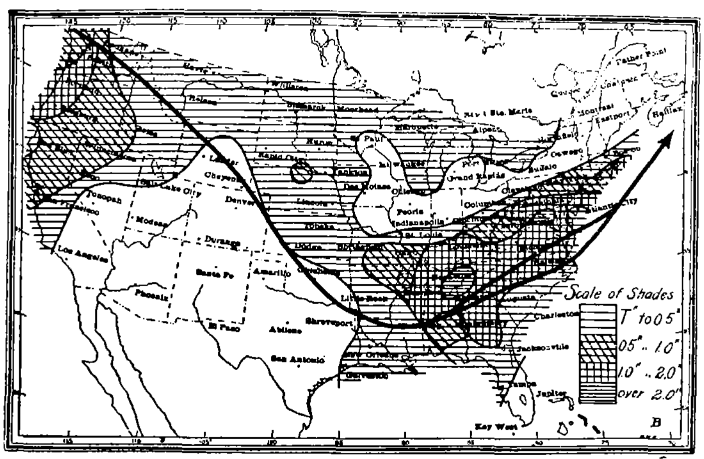

FIG. 3.—Path of a cyclone, Dec. 1-7, 1910, from the Pacific coast to Nova Scotia, on a southern track. Heavy precipitation west of the Rocky Mountains to the right of the track; east of the Rocky Mountains to the left of the track.

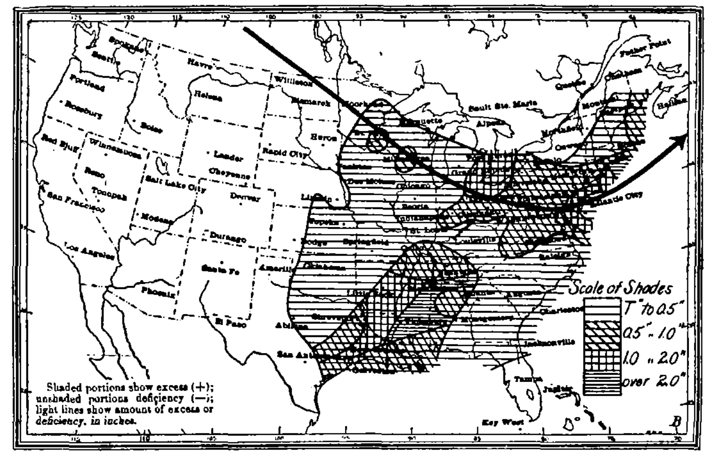

FIG. 4.—Path of a cyclone, Apr. 16–22, 1911, entering the United States from Canada already formed. Heavy precipitation on and to the left of the track. Heavy rainfall in the Gulf and lower Mississippi Valley regions due in part to thunderstorm rains.

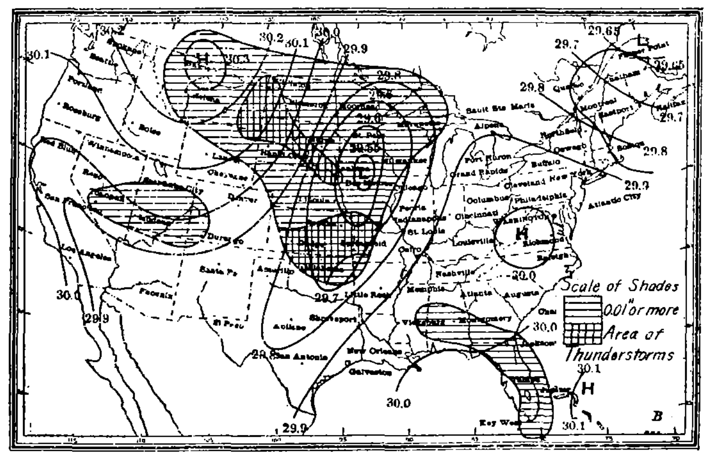

FIG. 5.—Typical case of thunderstorm rains included in the general rain area of a cyclone, July 23, 1911, pressure at 8 a. m., 75th meridian time, rainfall for the past 24 hours.

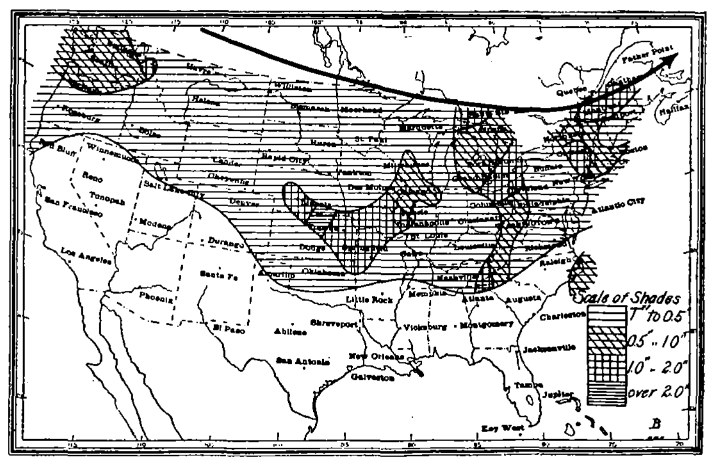

FIG. 6.—Areas of heavier precipitation much broken by areas of lighter rainfall. Cyclone track wholly in Canada. Heavier rainfall probably to the right of the track. Period, May 23 to June 3, 1910.

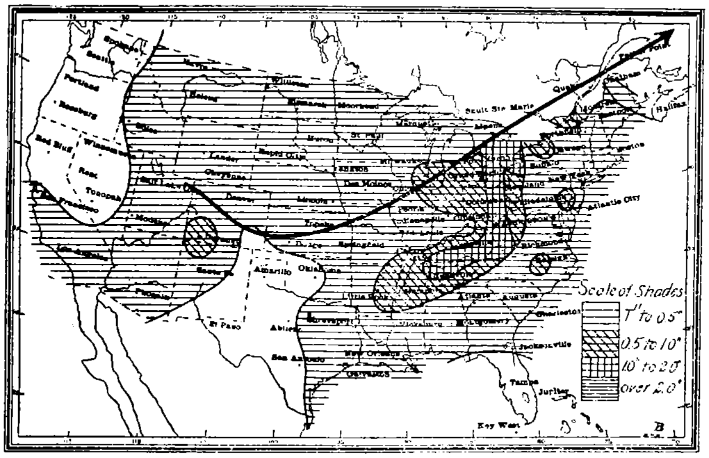

FIG. 7.—Cyclone of Jan. 16–19, 1910, on a central track. Heavy precipitation to the right of the track. Mississippi River and Lake influence on rainfall.

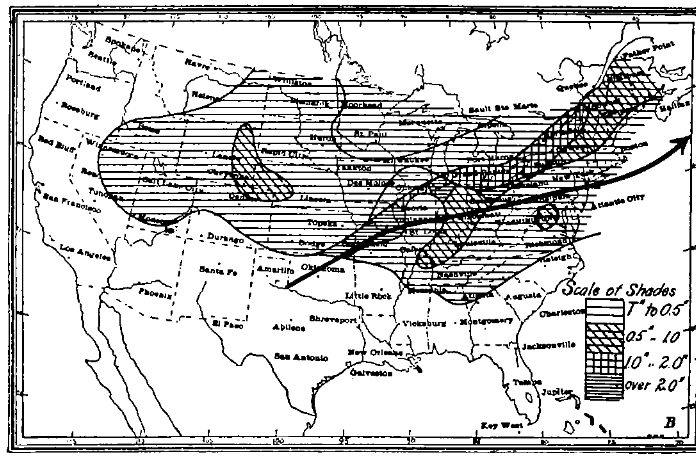

FIG. 9.—Cyclone, Apr. 30–May 5, 1910, on a central track. Heavy precipitation on and to the left of the track. Mississippi River and Lake influence on rainfall.

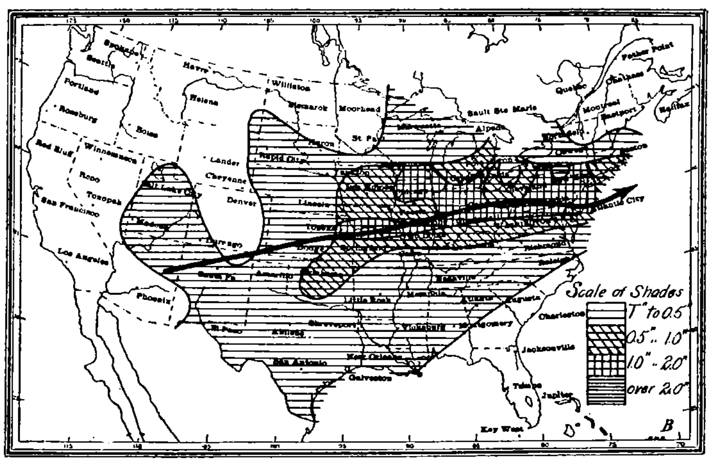

FIG. 8.—Cyclone, Jan. 1–16, 1911, on a central track. Heavy precipitation on the track. Mississippi River, Lake, and Atlantic Ocean influence on rainfall.

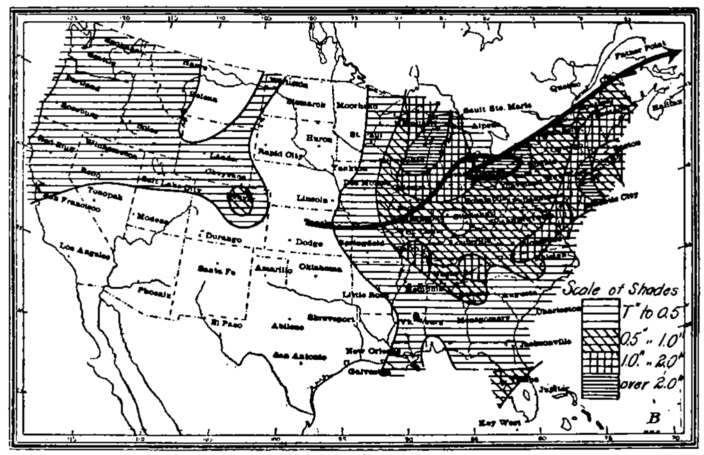

FIG. 10.—Areas of precipitation completely separated by areas of no rain. Lake and Atlantic Ocean and slight Pacific Ocean influence on rainfall. Track between two areas of heavy rainfall. Period, Apr. 19–28, 1910.

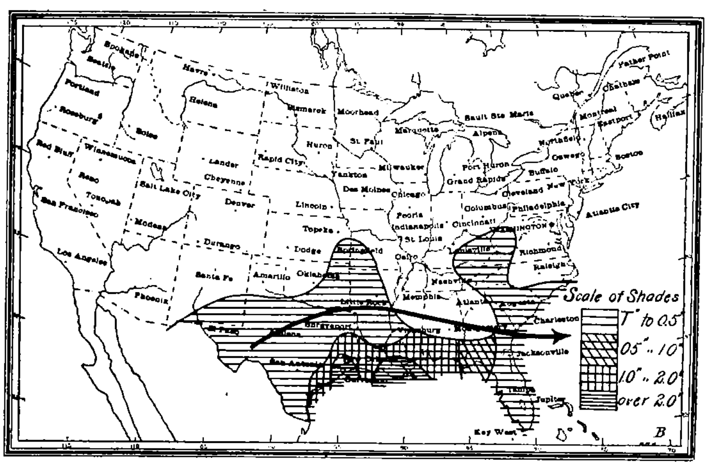

FIG. 11.—Cyclone, Mar. 22–24, 1911, on a southern track. Gulf and Atlantic Ocean influence on rainfall. Heavy rainfall to the right of the track.